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COST EFFECTIVE ROAD MAINTENANCE STRATEGIES FOR THE FOREST DEVELOPMENT ROAD SYSTEM

USDA FOREST SERVICE

jmk
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BY

DONALD HABER

COMPETION REPORT

INT-91614 RJVA AMENDMENT 1

FINAL REPORT FOR RESEARCH AGREEMENT
#INT-91614-RJVA
"Complete the O&M Strategies Study and
Coordinate a Series of Transporation Studies
Ongoing at SDTDC and INT"
UNIVERSITY OF IDAHO
FS Contact: Dr. M. Dean Knighton
CoOp Contact: Dr. Donald F. Haber

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INTRODUCTION

In 1992, the USDA Forest Service commissioned research into examining economic models for road maintenance and reconstruction especially for low volume, aggregate surface roads. If models could be found that adequately predicted road surface conditions under various maintenance alternatives, the cost of road maintenance and vehicle operating cost could be estimated given appropriate cost and environmental inputs. The consequences of proposed budgets for road maintenance and reconstruction on the condition of the road system and the cost of vehicle operation could be illustrated.

The Highway Design and Maintenance Standards Model developed by the World Bank has the ability to quantify and predict performance and cost functions for large and diverse road network. This model focuses on the rigorous empirical quantification of the tradeoffs between the costs of road maintenance and vehicle operation. In addition on the development of planning models incorporating total life-cycle cost simulation as a basis for road decision making. Because of the Highway Design and Maintenance Model's ability to incorporate cost of aggregate road maintenance with road performance, it was chosen for this study.

Approximately two thirds of all road maintenance costs for the Forest Development Road System is expensed on aggregate surface roads maintained at an intermediate level of service (level III). The cost of maintaining these roads at this service level is a major part of the transportation maintenance and reconstruction budget. This report examines typical samples of aggregate roads in three Forests that are maintained at a service level III . The roads were chosen such that they represent the average geometry, aggregate, and traffic characteristics of roads of this type.

MAINTENANCE STRATEGIES

Seven maintenance alternatives were used in the analysis. These seven alternatives along with the necessary unit costs were developed from consultations with Forest Maintenance Supervisors. They represent the present maintenance practices in addition to other potential alternatives that might be realized given budget constraints. All seven strategies are applied over a 30 year analysis period and the economic analysis carried out in today's dollars (inflation is not estimated).

Maintenance strategies ALT0 through ALT4 are those in which road blading is done on a set periodic time or when the road surface condition deteriorates beyond a set surface roughness. Surface aggregate is added when the thickness of the aggregate decreases below a set value (such as 2 inches). These strategies are estimated to preserve the integrity of the road surface. Reconstruction of the road prism is not necessary during the analysis period unless traffic volume increases requiring higher standard road.

Maintenance strategies ALT5 and ALT6 are those which are estimated to represent the "do nothing" or deferred maintenance approach. It was estimated from past cost records, that reconditioning of the road prism is necessary after a certain time if a minimal maintenance policy is followed even if the standard of the road remains the same. For all Forests, it was estimated that reconstruction costs after15 years (ALT5) would be $15,000 /mi. and if the deferred cost approach is followed for 30 years (ALT6) the costs would be $30,000 /mi.

All strategies assume the road is kept open over the 30 year period and the traffic volume (ADT) does not change. Maintenance of the culverts and periodic brushing of the shoulders is assumed for all alternatives even the "do nothing" ALT5 and ALT6. The road surface becomes extremely rough for ALT5 and ALT6 so road grading is done only if the road surface roughness reaches an extreme value. Traffic volume is assumed constant for all values of roughness.

Recent research has shown that a rough road with ruts greatly increases the sediment flow off the road surface. These environmental type effects were not taken into account in any of the maintenance cost estimates. In the Nez Perce Forest, ALT5 and ALT6 would represent an environmentally unacceptable maintenance policy unless the road was closed.

Complete detailed inputs and outputs for all analyses are presented in Appendix A. Summarized inputs and outputs are given in the following sections.

BOISE NATIONAL FOREST

The Boise Forest has two distinct geologic regions that determine the type of maintenance given to the road system. The lower elevation and eastern portions of the forest are typical of the basalt regions of Idaho with the roads generally having a crushed aggregate surface with fairly mild grades and curvature. In the other region, roads are constructed on decomposed granite. The elevation and curvature of the roads in the decomposed granite vary between mild grades and curvature in the lower elevations to extreme grades and curvature in the higher elevations. Because of the differences in surfacing and road geometry in the Boise, three typical sections were chosen to represent the three regions.

BASALT REGION

The maintenance polices for the basalt region is similar to those used in the Nez Perce Forest. Blading and aggregate replacement are done on a periodic or need basis. The resurfacing is crushed aggregate and the unit cost is fairly consistent with the Nez Perce Forest. The major maintenance difference between the Nez Perce and Boise Forests in the basalt region is the frequency of aggregate replacement.

DECOMPOSED GRANITE REGIONS

Maintenance practices are substantially different for the decomposed granite regions. Instead of hauling in crushed aggregate, either the road surface is "raked" to increase the fines or decomposed granite surfacing material is hauled in from nearby sources. These two surfacing methods have substantially lower unit costs as compared to the crushed aggregate surfacing. Also road geometry varies considerably from the lower to the higher elevation regions therefore the DG region was divided into two analyses, regular and steep.

NEZ PERCE FOREST

The Nez Perce Forest aggregate road system was modeled by assuming a road profile with fairly mild grades and curvature. Because of environmental constraints, road surfacing was done when the aggregate thickness reached an average of one and a half of inches as a standard maintenance practice. The characteristics of the aggregate surfacing were similar to the Boise, that is, crushed and graded aggregate. Also, the "do nothing" alternatives were essentially the same as that used for the Boise Forest.

GIFFORD PINCHOT FOREST

A typical road section in the Windriver District of the Gifford Pinchot Forest was modeled for the analysis. Aggregate surfacing characteristics, frequency of blading and thickness of resurfacing differentiated this analysis from the other two.

FOREST SUGGESTED MAINTENANCE STRATEGY SUMMARY

AGGREGATE-BOISE

OPERATION	UNIT COST	STRATEGY						
	$/unit	ALTO	ALT1	ALT2	ALT3	ALT4	ALT5	ALT6
BLADE	135 $/mi	2 times season	2 times season	1 time season	1 time season	QI 150	QI 150	QI 150
SPOT	20 $/yd^3	—	30% loss	—	30% loss	—	—	—
RESURFACE (in)	20 $/yd^3	t<.4 t = 4	t<.4 t = 4.4	t<.4 t = 4.4	t<.4 t = 4.4	t<.4 t = 4.4	15 yrs	30 yrs
ROUTINE	230 $/mi-yr	yes	yes	yes	yes	yes	yes	yes
ROAD RECON-STRUCT	15000 to 30000 $/mi	no	no	no	no	no	yes 15000 $/mi	yes 30000 $/mi

DG-BOISE

BLADE	135 $/MI	4 times season	4 times season	2 times season	2 times season	QI 125	QI 150	QI 150
SPOT	5 yd^3	—	30% loss	—	30% loss	—	—	—
RESURFACE (in)	5 $/yd^3	t<.4 t = 4.4	t<.4 t = 4.4	t<.4 t = 4.4	t<.4 t = 4.4	t<.4 t = 4.4	15 yrs	30 yrs
ROUTINE	142 $/mi-yr	yes	yes	yes	yes	yes	yes	yes
ROAD RECON-SRUCT	15000 to 30000 $/mi	no	no	no	no	no	yes 15000 $/mi	yes 30000 $/mi

DG ROCK RAKE-BOISE

BLADE	135 $/mi	2 times season	2 times season	1 time season	1 time season	QI 150	QI 150	QI 150
SPOT RAKE	.30 $/yd^3	—	30% loss	—	30% loss	—	—	—
RESURFACE RAKE (in)	.30 $/yd	t<.4 t = 4.4	t<.4 t = 4.4	t<.4 t = 4.4	t<.4 t = 4.4	t<.4 t = 4.4	15 yrs	30 yrs
ROUTINE	190 $/mi-yr	yes	yes	yes	yes	yes	yes	yes
ROAD RECON-STRUCT	15000 to 30000 $/mi	no	no	no	no	no	yes 15000 $/mi	yes 30000 $/mi

MAINTENANCE STRATEGIES (CONTINUED)

HORSECREEK- NEZ PERCE

OPERATION	UNIT COST	STRATEGY						
	$/unit	ALT0	ALT1	ALT2	ALT3	ALT4	ALT5	ALT6
BLADE	138 $/mi	4 times season	4 times season	1 time season	1 time season	QI 100	15 yrs	30 yrs
SPOT	12 $/yd^3	—	30% loss	—	30% loss	—	—	—
RESURFACE (in)	12 $/yd^3	t<1.5 to t = 4	t<1.5 t = 4	t<1.5 t = 4	t<1.5 t = 4	t<1.5 t = 4	15 yrs	30 yrs
ROUTINE	200 $/mi-yr	yes	yes	yes	yes	yes	yes	yes
ROAD RECON-STRUCT	15000 to 30000 $/mi	no	no	no	no	no	yes 15000 $/mi	yes 30000 $/mi

WINDRIVER DISTRICT- GIFFORD PINCHOT

BLADE	106 $/mi	4 times season	4 times season	1 time season	1 time season	QI 100	15 yrs	30 yrs
SPOT	9 $/yd^3	—	30% loss	—	30% loss	—	—	—
RESURFACE (in)	9 $/yd^3	t<0.4 t = 6	t<0.4 t = 6	t<0.4 t = 6	t<0.4 t = 6	t<0.4 t = 6	15 yrs	30 yrs
ROUTINE	230 $/mi-yr	yes	yes	yes	yes	yes	yes	yes
ROAD RECON-STRUCT	15000 to 30000 $/mi	no	no	no	no	no	yes $15000	yes $30000

TRAFFIC VOLUME AND TYPE

TRAFFIC VOLUME

The traffic volume used by the HDM model is an average daily figure assumed to be constant for an entire year. Because roads in the three Forest's generally are closed (impassable) for periods during the winter, an adjusted seasonal daily traffic level was determined.

A yearly average daily traffic level (ADT) of 45 vehicles was used in first analysis set. The actual seasonal ADT (nine month road season) suggested by the Windriver District was 60. This ADT was reduced to 45 to reflect the nine month road season. Although the open road season for both the Boise and the Nez Perce was closer to six month and the seasonal ADT's were generally lower then 60, a yearly ADT of 45 was kept for the first set of analyses for comparison purposes. A more realistic ADT of 22 was used for the for the Boise (all three cases) and the Nez Perce in the optimum maintenance analysis section.

A vehicle mix consisting of 10 loaded and 10 unloaded logging trucks along with 25 pickups was used in the first analysis. For the Optimal Analysis Section, 5 loaded and 5 unloaded logging trucks along with 12 pickups were the estimated traffic mix for the Boise and Nez Perce analyses. The vehicle mix remained constant for all Windriver analyses. It was also assumed the ADT did not change with road surface roughness for the 30 year period.

VEHICLE OPERATING COSTS (VOC)

The vehicle operating costs (VOC) are calculated based on an algorithm developed using data from Brazil and include predictions of :

1. Average operating speed;
2. Resources used:
    - (a) Fuel
    - (b) Tire wear
    - (c) Maintenance parts
    - (d) Maintenance labor
    - (e) Lubricants
    - (f) Crew
    - (g) Depreciation
    - (h) Interest
    - (i) Overhead
    - (j) Cargo holding
    - (k) Miscellaneous costs

Where possible, inputs were updated to reflect average logging truck and pickup truck values. The updated values were determined from manufacture's data or estimated with consultation with Forest Road Maintenance Supervisors. All input data is shown in APPENDIX A. All analysis used the same vehicle cost data.

SUMMARY OF ROAD GEOMETRY

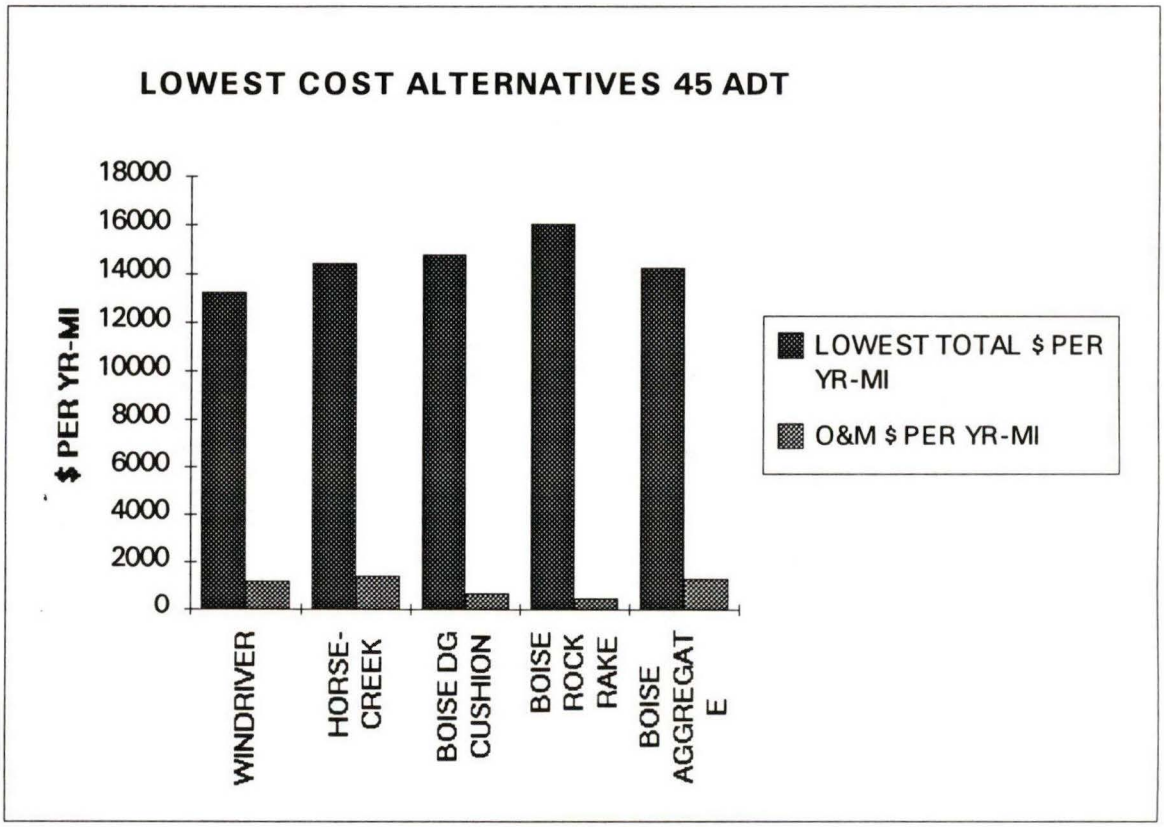
	ALTITUDE (ft)	AVERAGE GRADE	HORIZONTAL CURVE (°/mi)	WIDTH (ft)
WINDRIVER	1850	4%	311	14
HORSECREEK	5100	4%	400	14
BOISE AGG	3000	4%	500	14
BOISE DG	4500	6%	500	14
BOISE RAKE	6500	7 %	1020	14

SUMMARY OF ROAD SURFACING CHARACTERISTICS

	AGGREGATE THICKNESS (in)	MAXIMUM PARTICLE SIZE (in)	MATERIAL PASSING 2 mm SIEVE (%)	MATERIAL PASSING .424 mm SIEVE (%)	MATERIAL PASSING .075 mm SIEVE (%)
WINDRIVER	6	.75	30	20	5
HORSECREEK	4	1.5	45	30	14.5
BOISE AGG	4.4	1.0	32	11	2
BOISE DG CUSH	4.4	.5	46	6	2
BOISE RAKE	4.4	1.5	61	34	9

ANALYSIS OF RESULTS 45 ADT

The figure below illustrates a comparison between the lowest total cost alternatives for each regional road. Although the maintenance costs for the Boise Rock Rake Roads are by far the smallest, the total cost per vehicle-mile is the highest. This is due to the VOC which is approximately 10 times higher then the road maintenance costs. VOC is sensitive to road roughness and those alternatives that produce the smallest mean yearly roughness are the most cost effective for overall costs.



ANALYSIS OF FIELD SUGGESTED MAINTENANCE ALTERNATIVES 45 ADT

The following table summarizes the lowest cost alternatives for total vehicle and road costs and illustrates the O&M costs per yr-mi associated with the alternative. The "best alternative" is ***only for those alternatives suggested by field personnel*** and is not necessarily the most cost effective alternative. For example, if the frequency of blading was increased the total cost would generally decrease until blading becomes so frequent the increased cost is more that that realized from a decrease in VOC costs. The section on optimal maintenance shows this type of approach.

Also, the lowest possible O&M cost listed in the table may not be environmentally feasible since deferring maintenance for a 30 yr period may cause unacceptable sediment runoff due to the road rutting and roughness.

LOWEST COST ALTERNATIVES

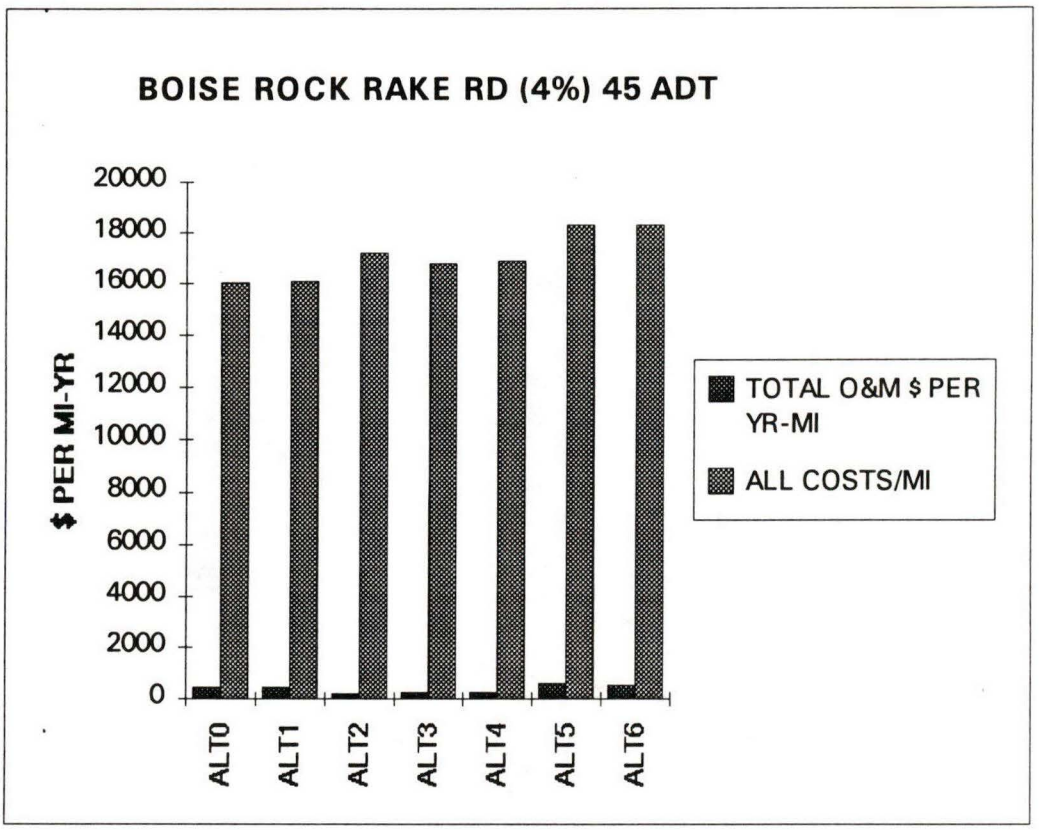
FOR TOTAL COST AND MAINTENANCE $ PER YR- MILE 45 ADT

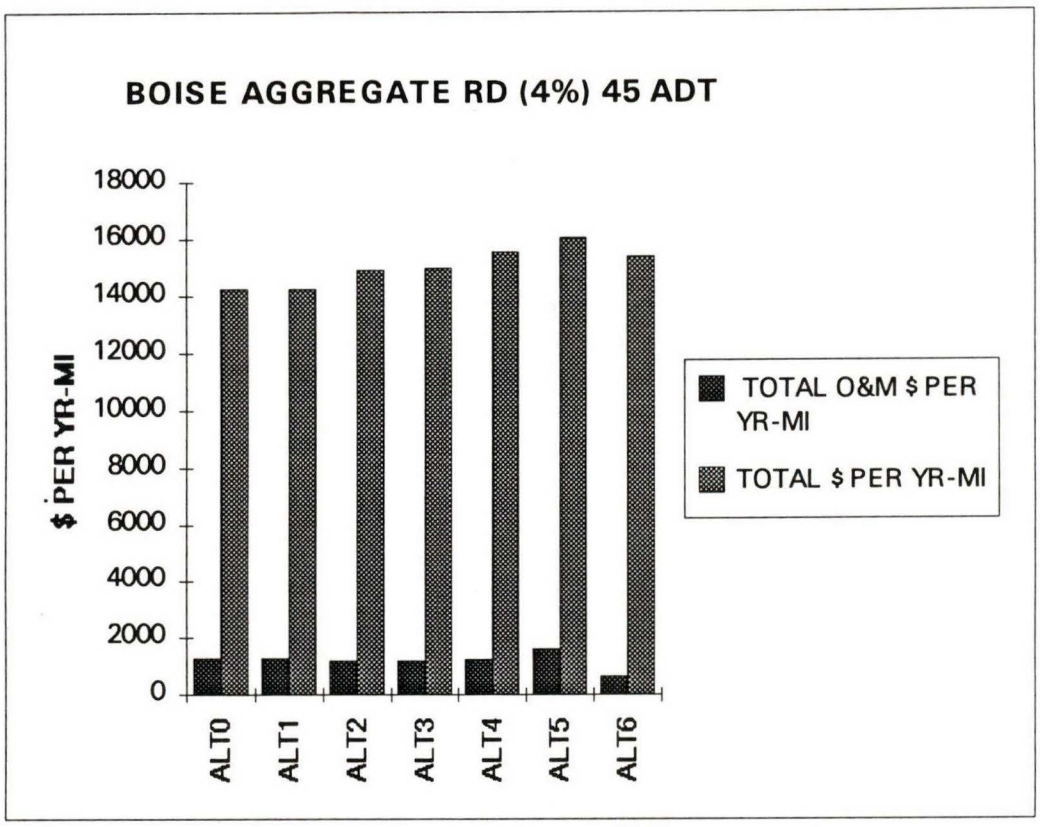
	LOWEST TOTAL COST $ PER YR-MI	O&M COST $ PER YR-MI	ALTERNATIVE	
WINDRIVER	13233	1213	ALT0	"Blade 4 times/season-resurface 6 in"
HORSECREEK	14433	1413	ALT0	"Blade 4 times/season-resurface 4 in"
BOISE DG CUSHION	14767	700	ALT0	"Blade 4 times/season-resurface 4 in"
BOISE ROCK RAKE	16033	220	ALT0	"Blade 4 times/season-resurface 4 in"
BOISE AGGREGATE	14233	1277	ALT0	"Blade 4 times/season-resurface 4 in"

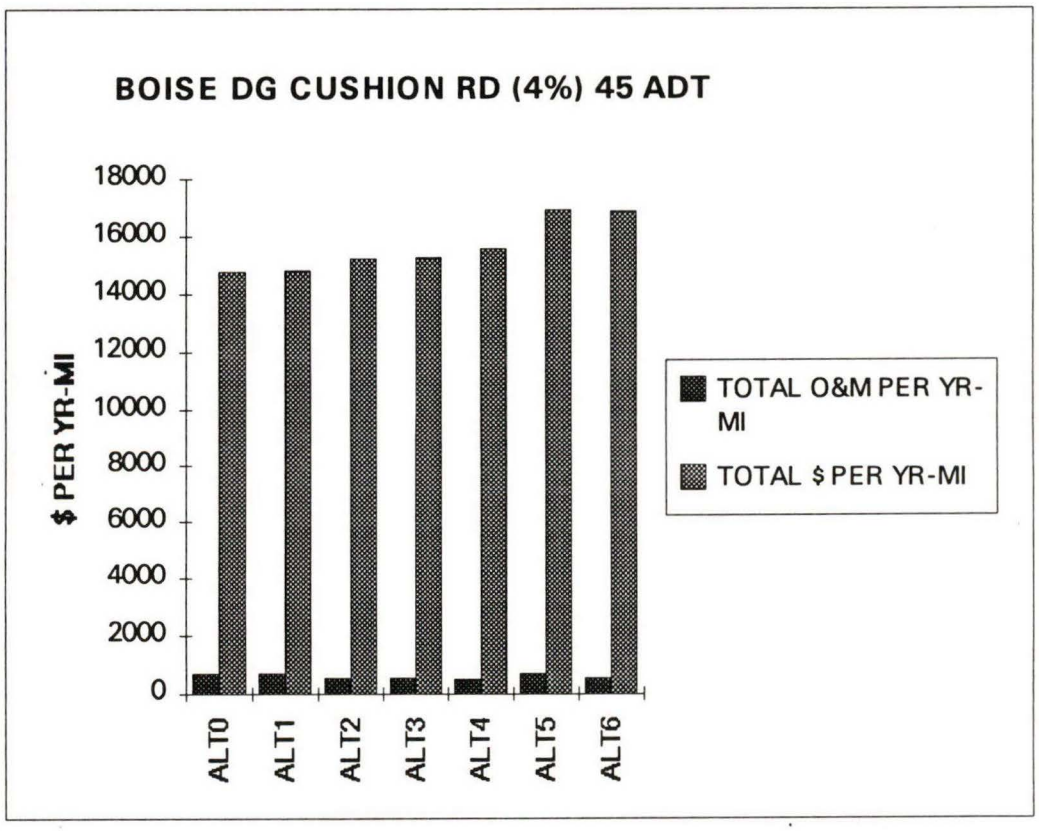
	LOWEST O&M COSTS	ALTERNATIVE	
WINDRIVER	403	ALT6	"Do nothing reconstruct after 30 yrs"
HORSECREEK	327	ALT6	"Do nothing reconstruct after 30 yrs"
BOISE DG CUSHION	480	ALT4	"Blade when roughness exceeds 125QI "
BOISE ROCK RAKE	220	ALT2	"Blade once a year. spot rake"
BOISE AGGREGATE	643	ALT0	"Do nothing reconstruct after 30 yrs"

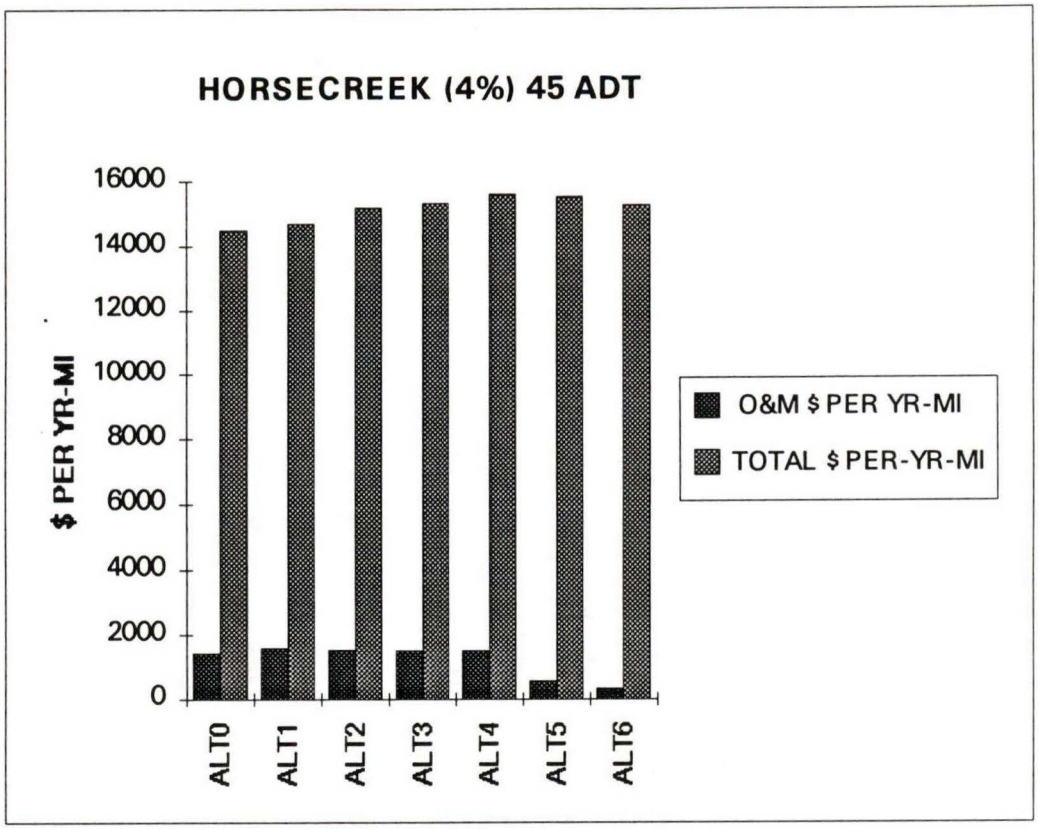
SUMMARY OF ALTERNATIVE COSTS FOR EACH REGIONAL ROAD

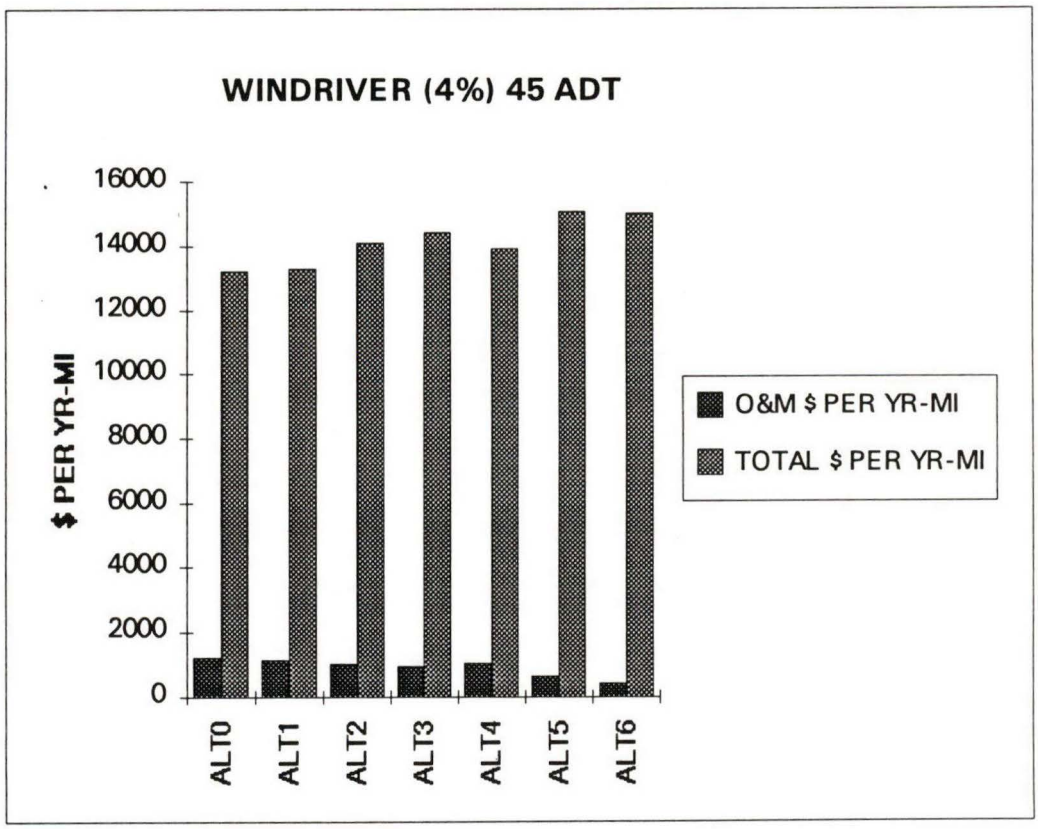
The following figures show the relative costs in $ per vehicle-mile for each alternative. A discount rate of 4% is used for each regional road.




BOISE AGGREGATE RD (4%) 45 ADT
$ PER YR-MI
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
ALT0
ALT1
ALT2
ALT3
ALT4
ALT5
ALT6
TOTAL O&M $ PER YR-MI
TOTAL $ PER YR-MI

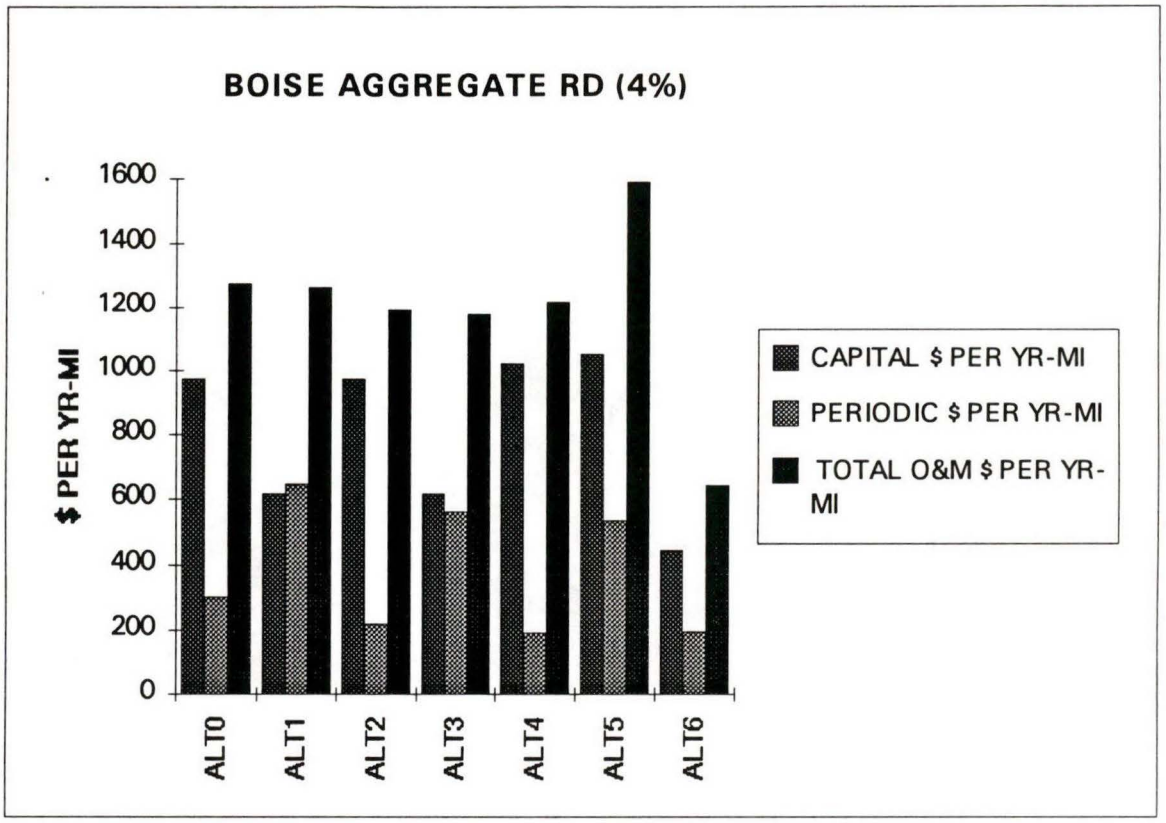

BOISE DG CUSHION RD (4%) 45 ADT
$ PER YR-MI
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
ALT0
ALT1
ALT2
ALT3
ALT4
ALT5
ALT6
TOTAL O&M PER YR-MI
TOTAL $ PER YR-MI

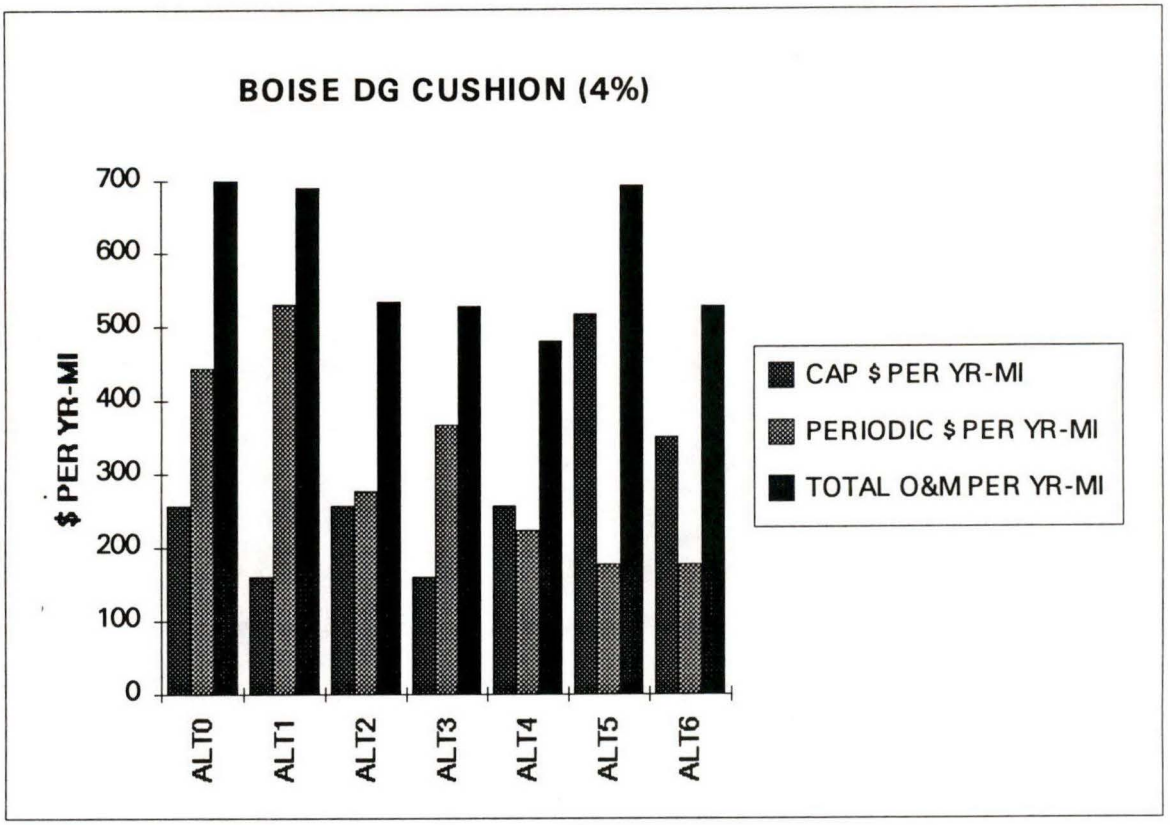

HORSECREEK (4%) 45 ADT
$ PER YR-MI
16000
14000
12000
10000
8000
6000
4000
2000
0
ALT0
ALT1
ALT2
ALT3
ALT4
ALT5
ALT6
O&M $ PER YR-MI
TOTAL $ PER-YR-MI

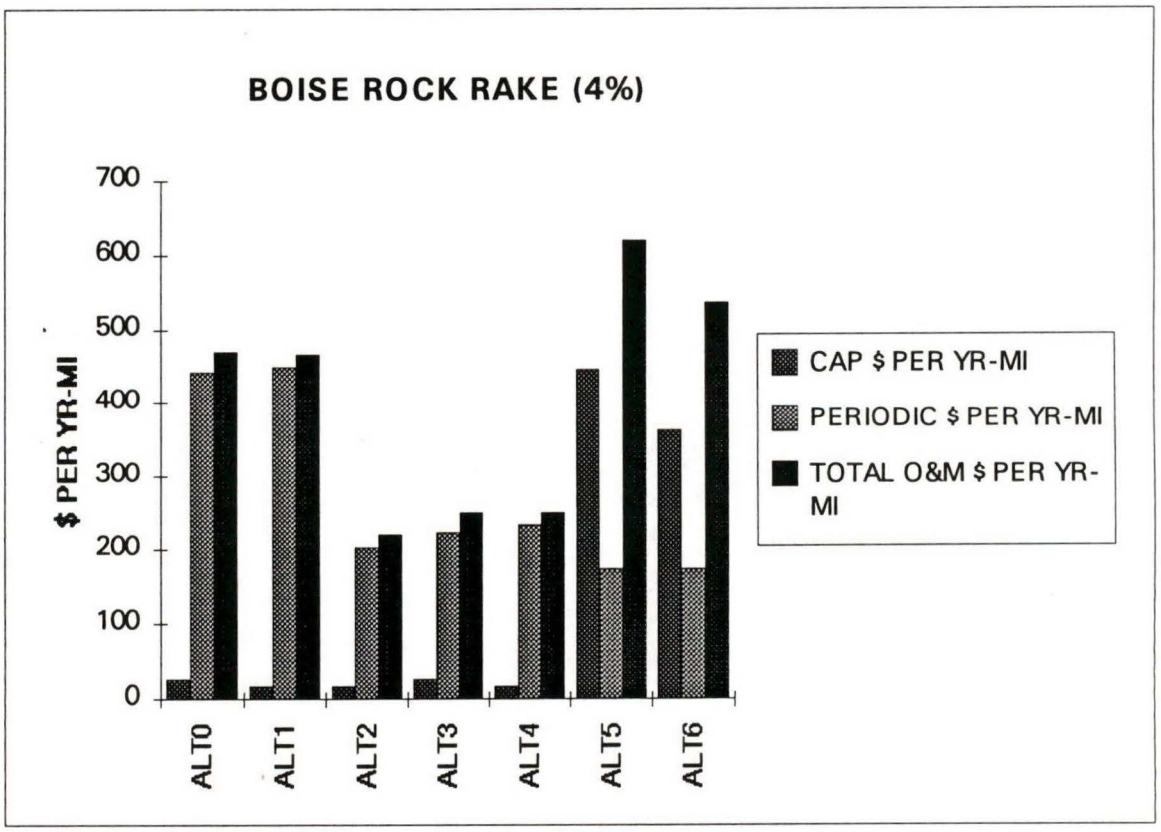

WINDRIVER (4%) 45 ADT
$ PER YR-MI
16000
14000
12000
10000
8000
6000
4000
2000
0
ALT0
ALT1
ALT2
ALT3
ALT4
ALT5
ALT6
O&M $ PER YR-MI
TOTAL $ PER YR-MI

SUMMARY OF YEARLY OPERATION AND MAINTENANCE COSTS

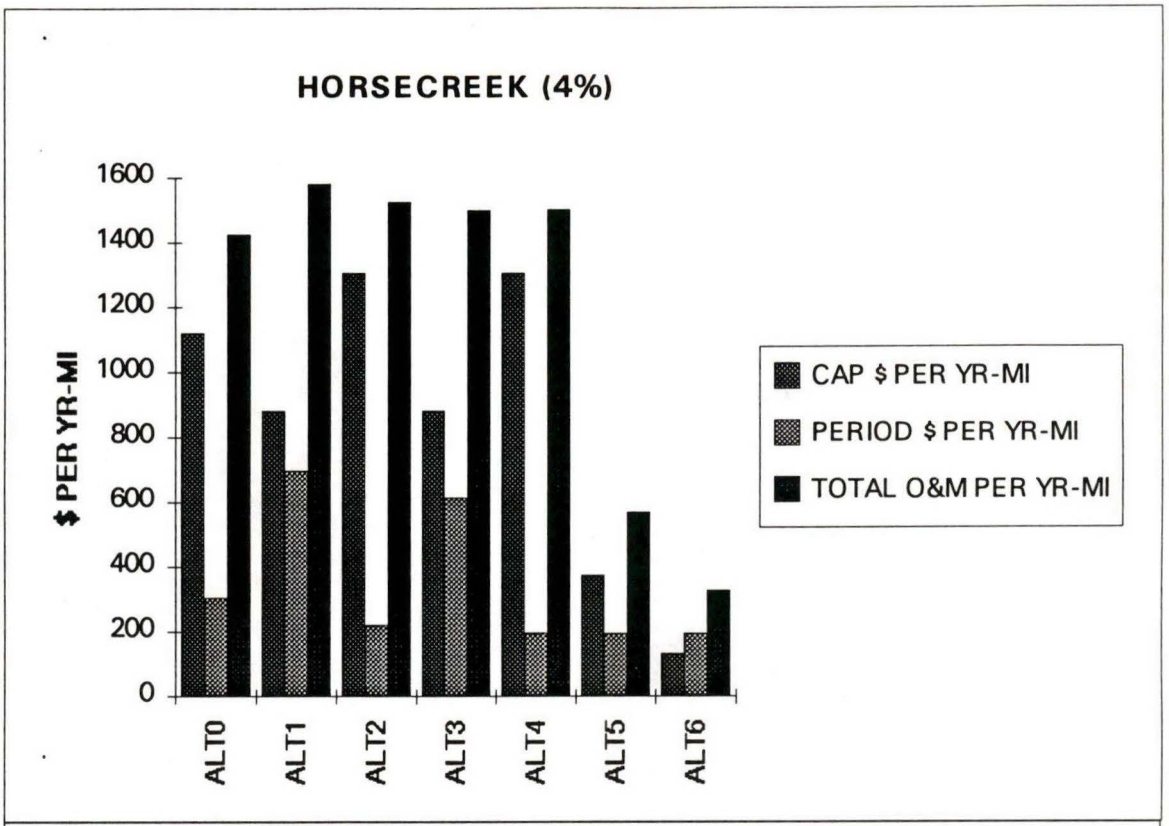
The following figures show the yearly maintenance costs per mi of road for the alternatives. Blading and routine maintenance is listed as periodic and prism reconstruction and resurfacing is listed as capital costs.

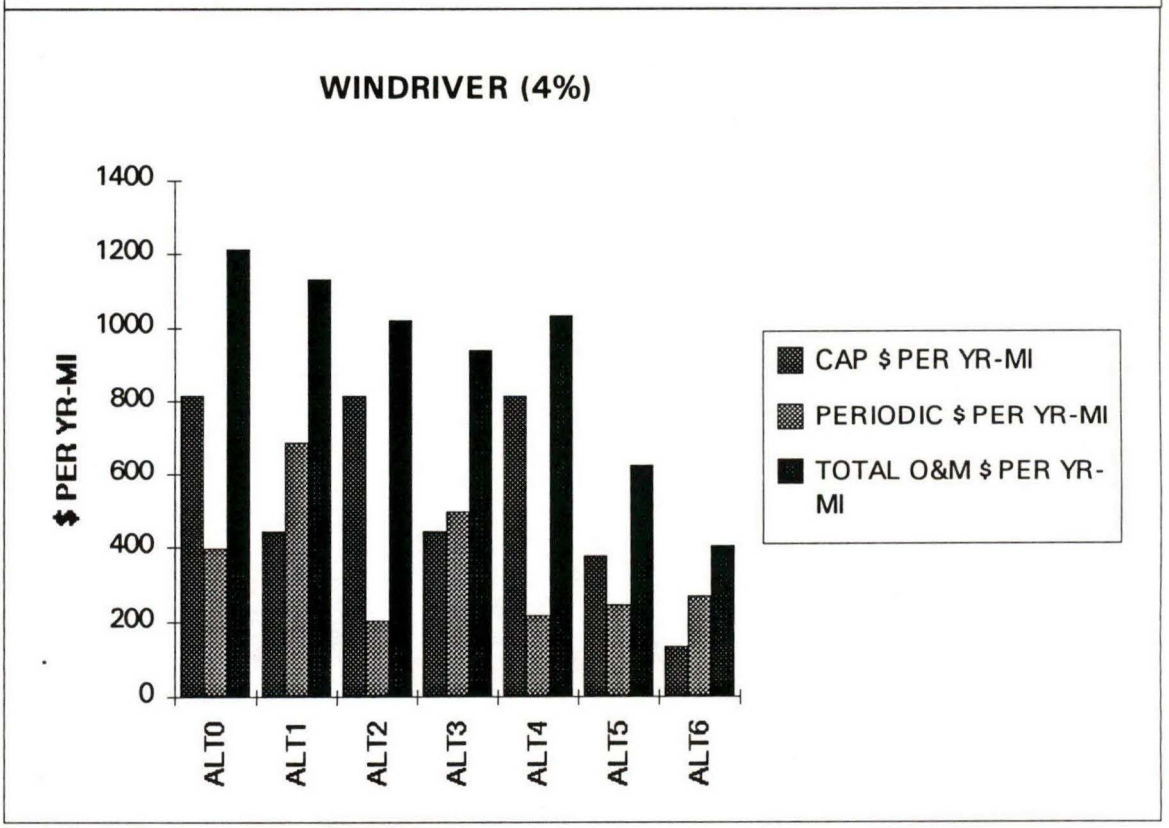



BOISE DG CUSHION (4%)
$ PER YR-MI
700
600
500
400
300
200
100
0
ALT0
ALT1
ALT2
ALT3
ALT4
ALT5
ALT6
CAP $ PER YR-MI
PERIODIC $ PER YR-MI
TOTAL O&M PER YR-MI


BOISE ROCK RAKE (4%)
$ PER YR-MI
700
600
500
400
300
200
100
0
ALT0
ALT1
ALT2
ALT3
ALT4
ALT5
ALT6
CAP $ PER YR-MI
PERIODIC $ PER YR-MI
TOTAL O&M $ PER YR-MI

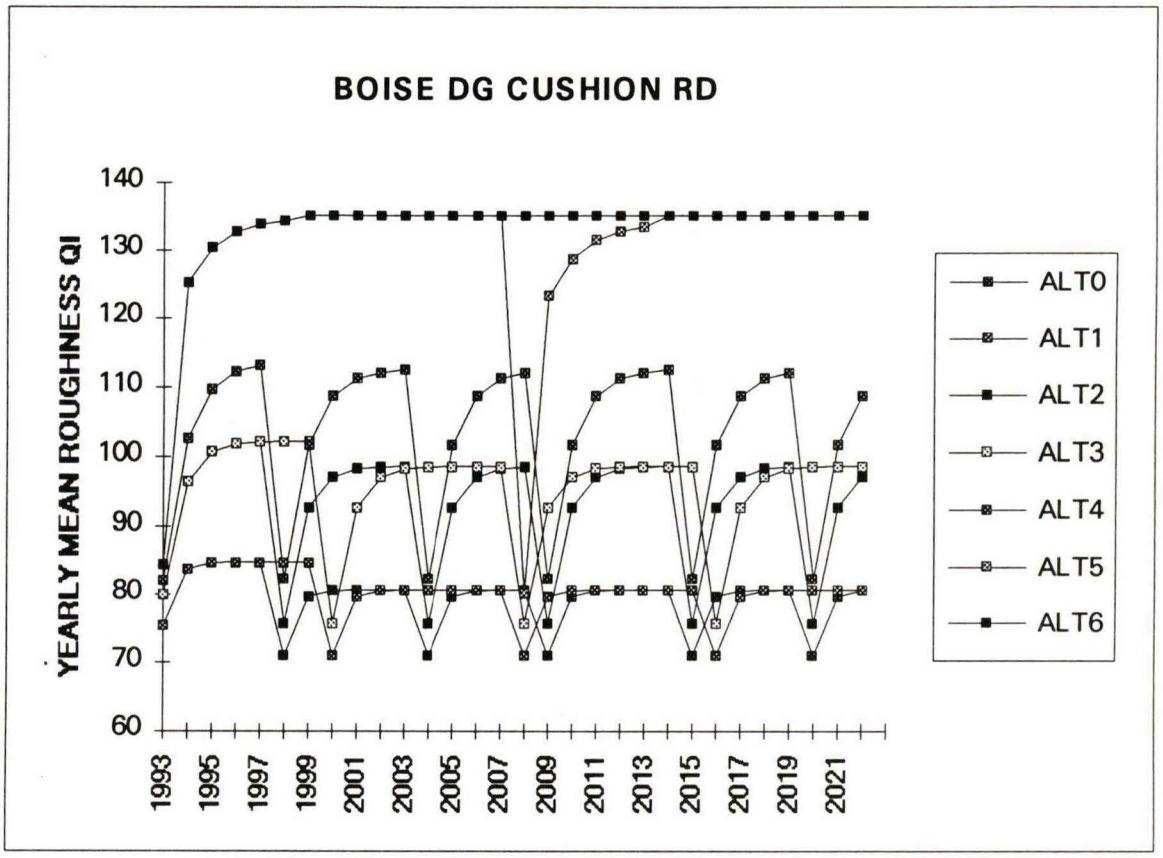
SUMMARY OF YEARLY MAINTENANCE COSTS (CONTINUED)

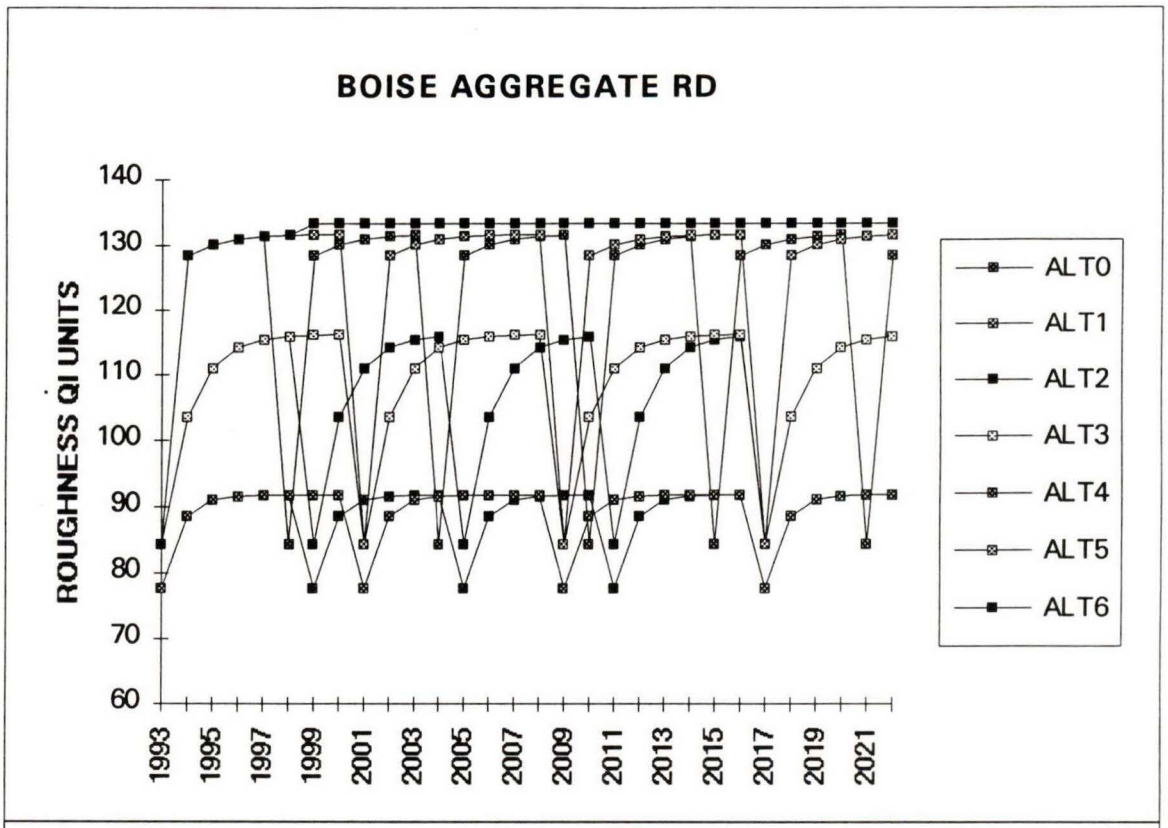


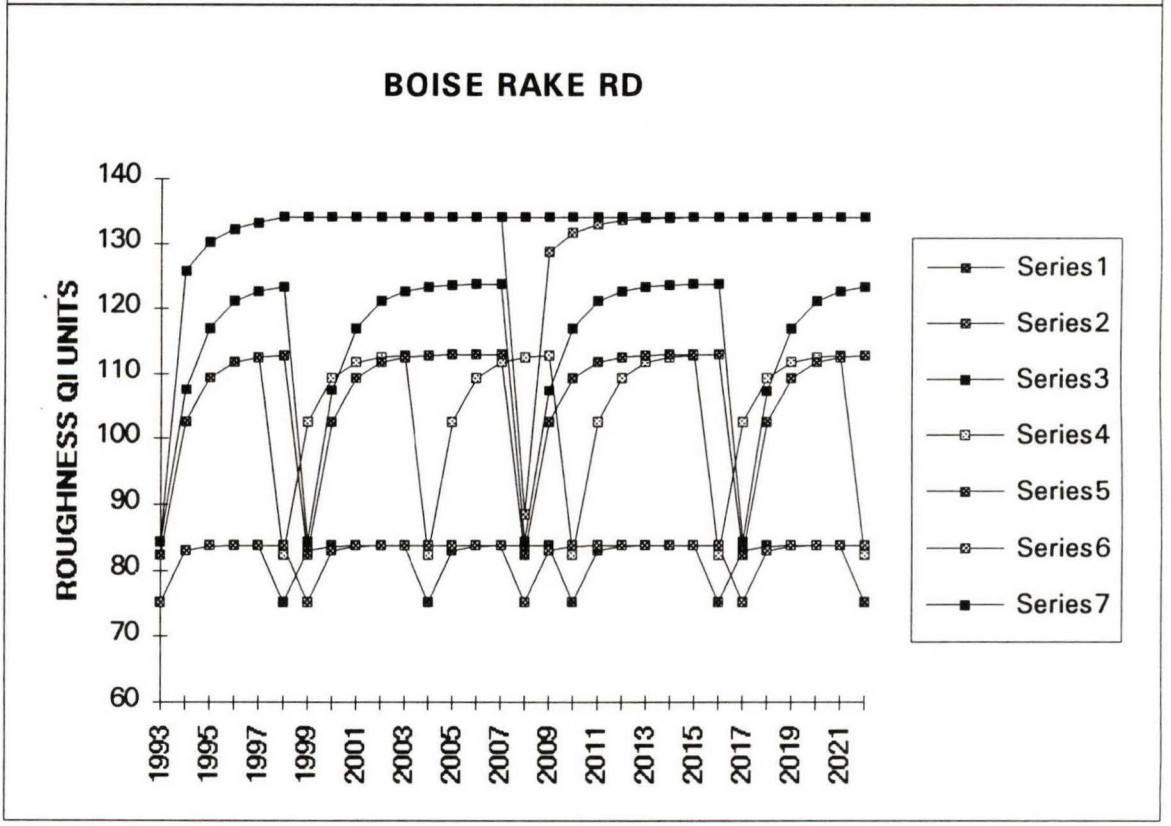


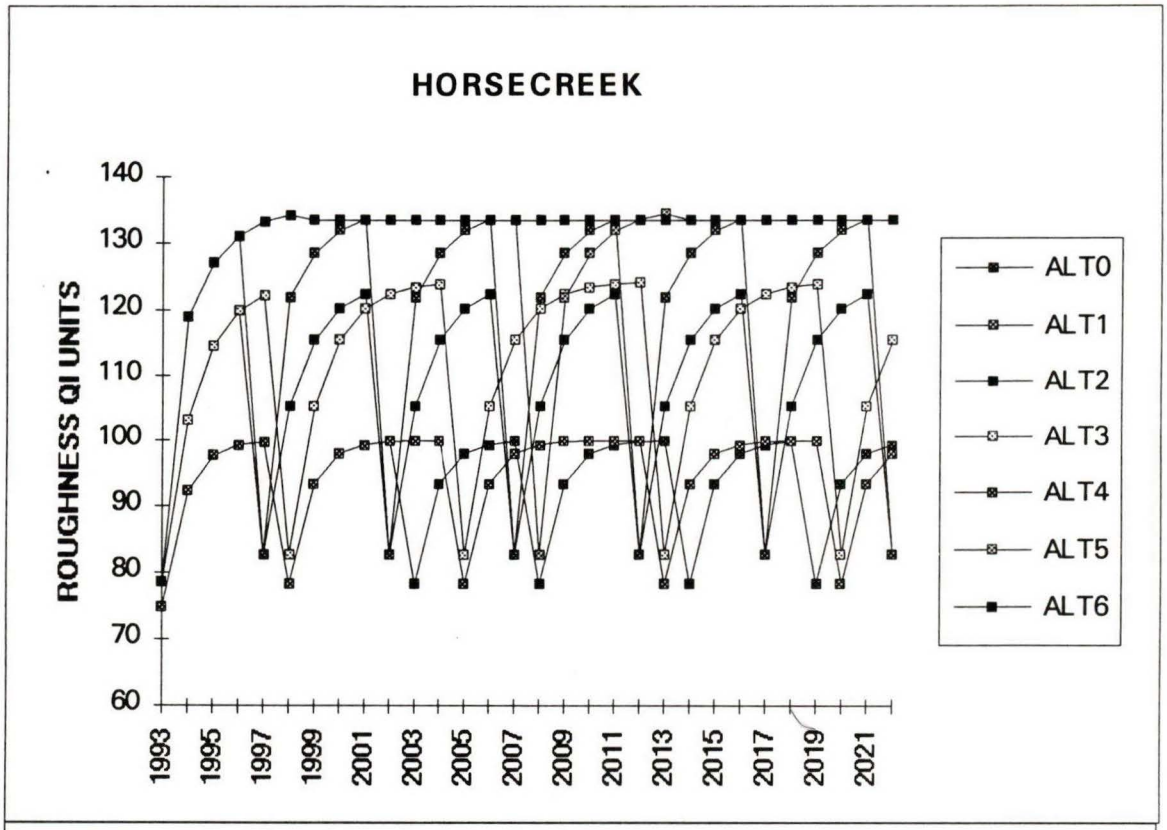
SUMMARY OF ROAD PREDICTED ROAD SURFACE CONDITIONS

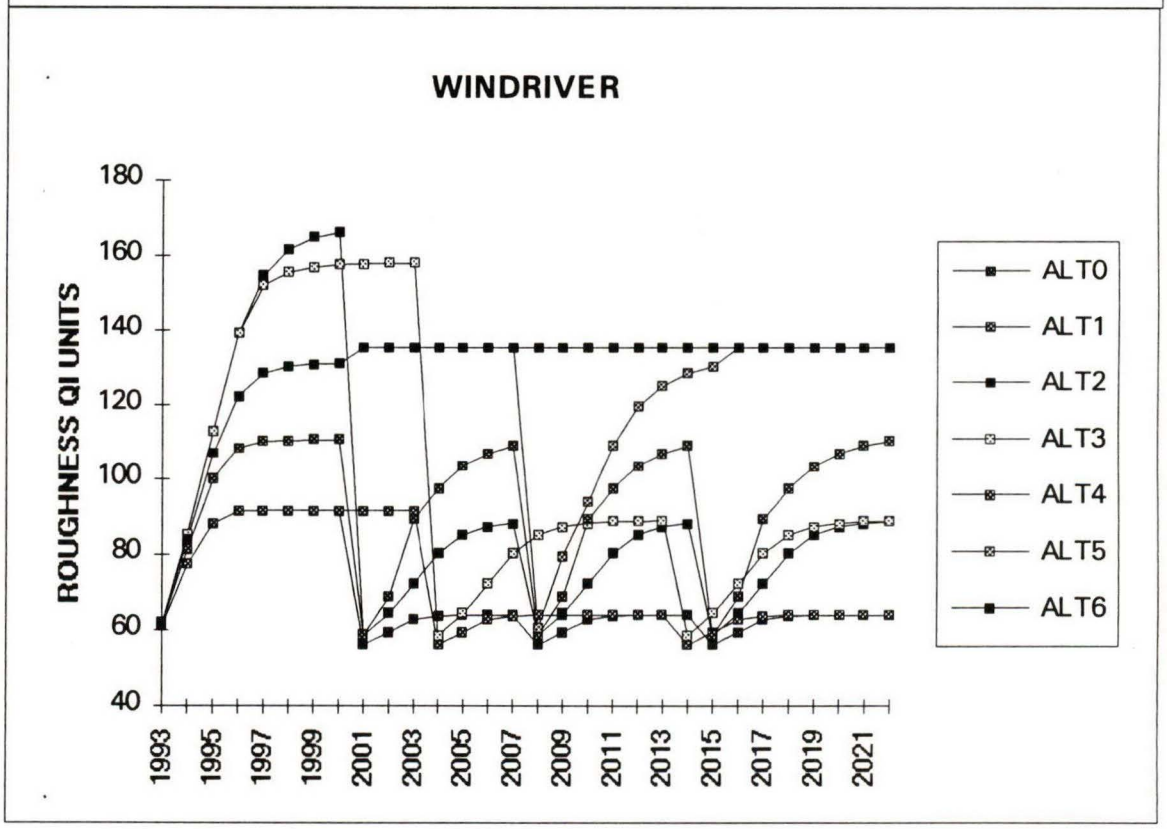
The following figures illustrate the predicted road surface roughness and thickness for a selected region. Appendix B has the predicted values for all regions modeled.




BOISE AGGREGATE RD
ROUGHNESS QI UNITS
140
130
120
110
100
90
80
70
60
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
2021
ALT0
ALT1
ALT2
ALT3
ALT4
ALT5
ALT6

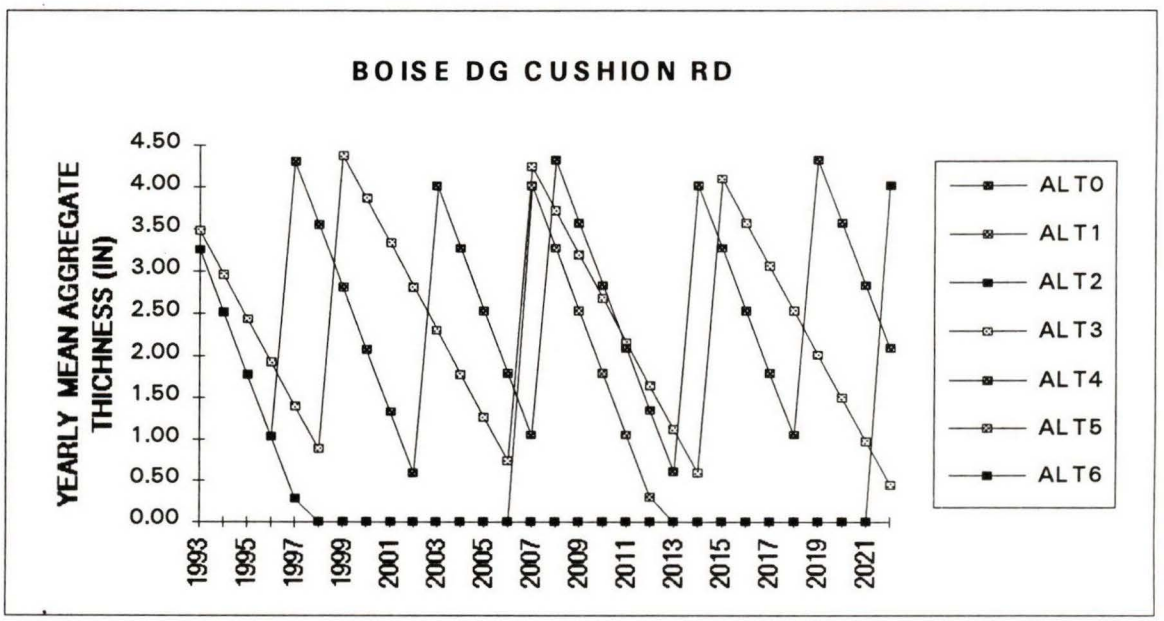

BOISE RAKE RD
ROUGHNESS QI UNITS
140
130
120
110
100
90
80
70
60
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
2021
Series1
Series2
Series3
Series4
Series5
Series6
Series7

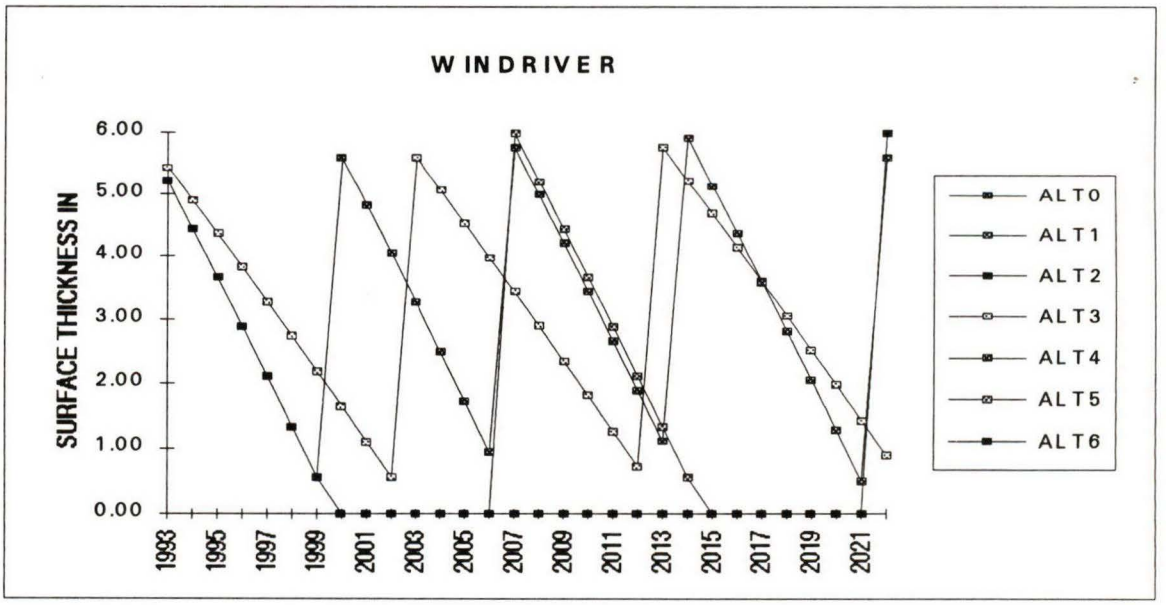

HORSECREEK
ROUGHNESS QI UNITS
140
130
120
110
100
90
80
70
60
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
2021
ALT0
ALT1
ALT2
ALT3
ALT4
ALT5
ALT6


WINDRIVER
ROUGHNESS QI UNITS
180
160
140
120
100
80
60
40
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
2021
ALT0
ALT1
ALT2
ALT3
ALT4
ALT5
ALT6

ALT5 and ALT6 the "deferred maintenance policies" have a very high mean yearly surface roughness (QI of 135) for most of the analysis period. A surface roughness of this magnitude would deter most of the recreational traffic from using the road. Logging trucks and pickup trucks that did travel the road would incur extremely high vehicle operating costs. ALT6 generally has the lowest yearly maintenance costs per mile of road. However, ALT6 has a higher the total cost per year (including VOC) than a better maintained road such as ALT0 where the mean yearly roughness is about 80 QI.

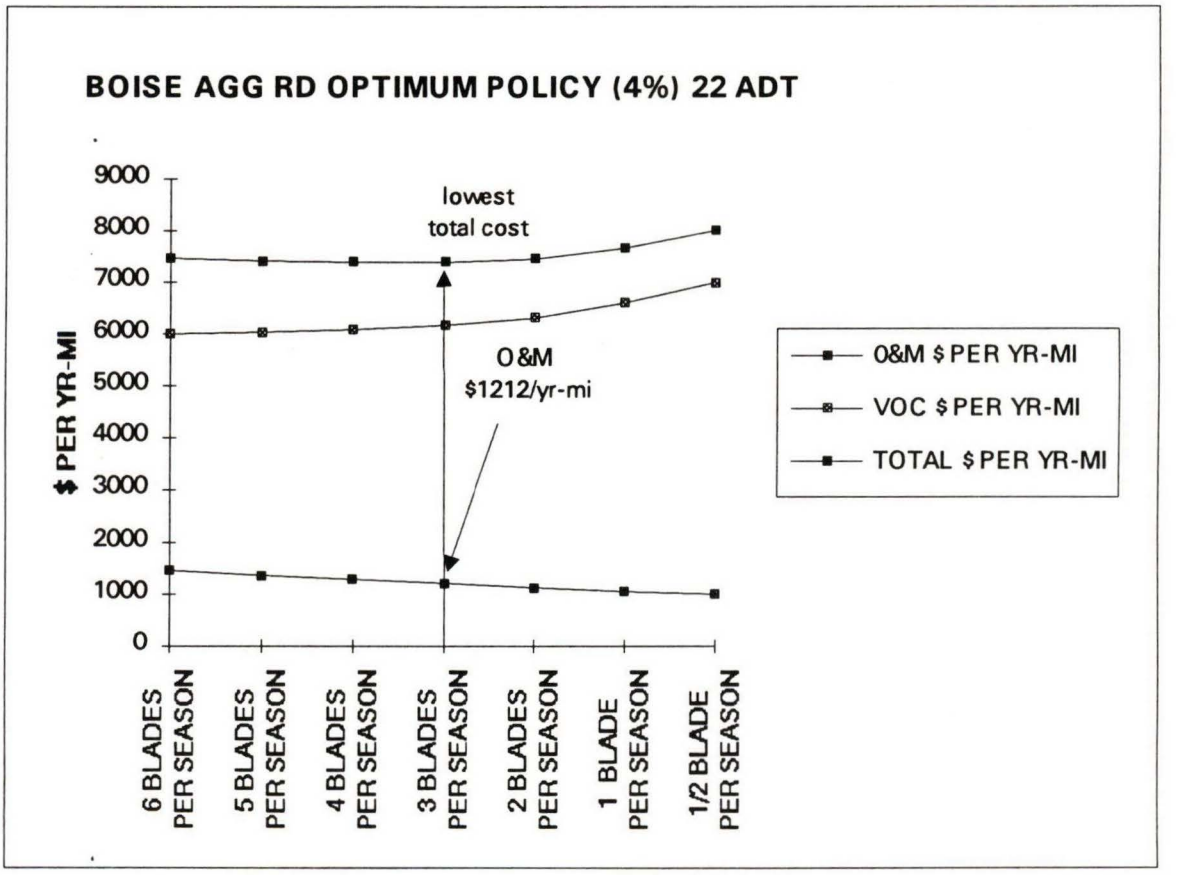
EXAMPLES OF AGGREGATE SURFACE THICKNESS WITH TIME

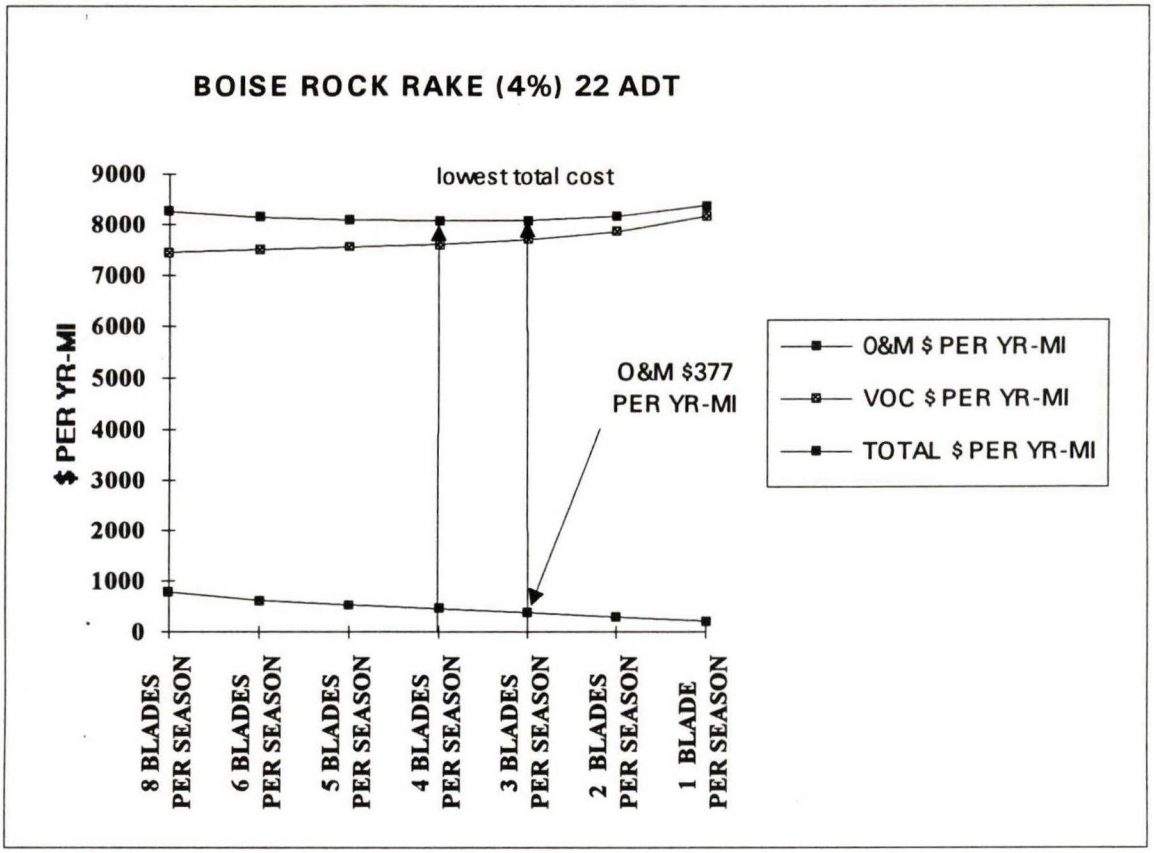


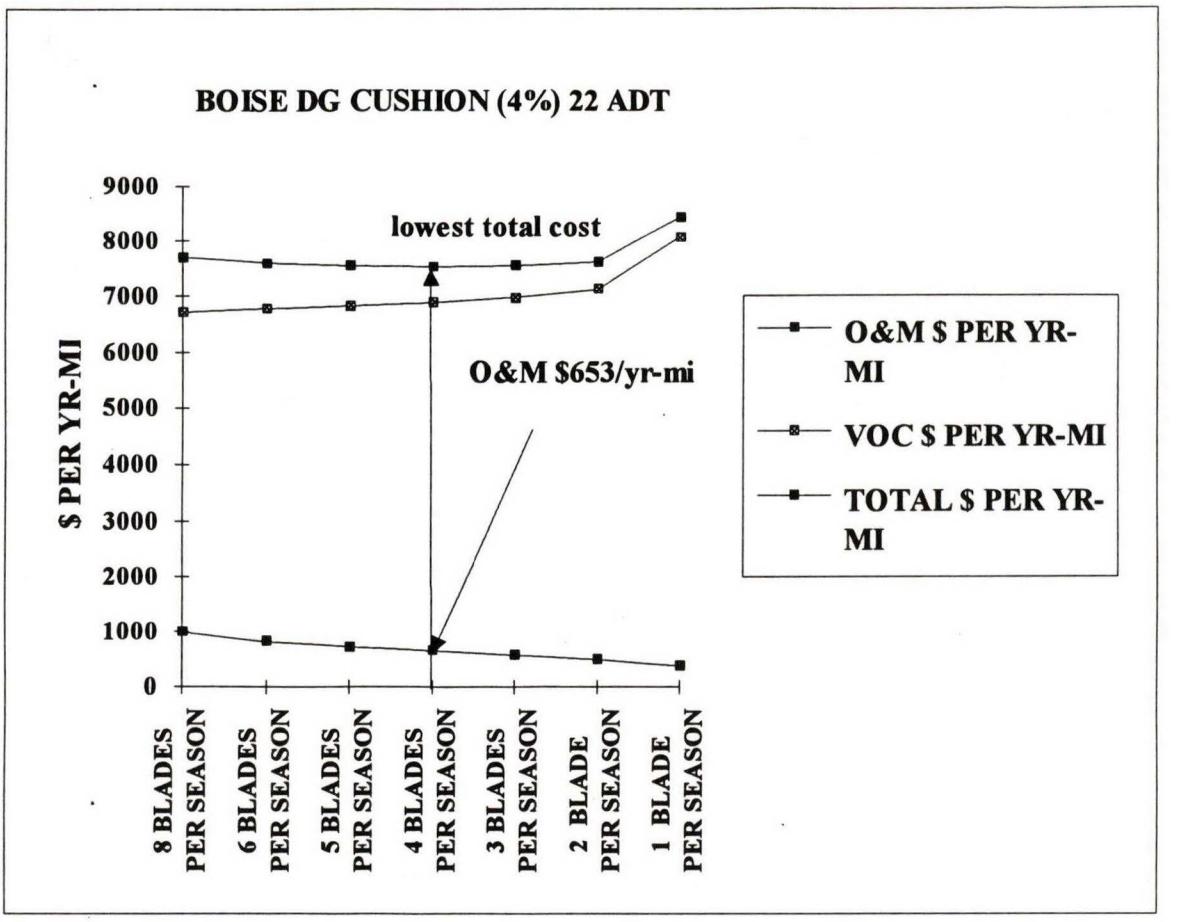


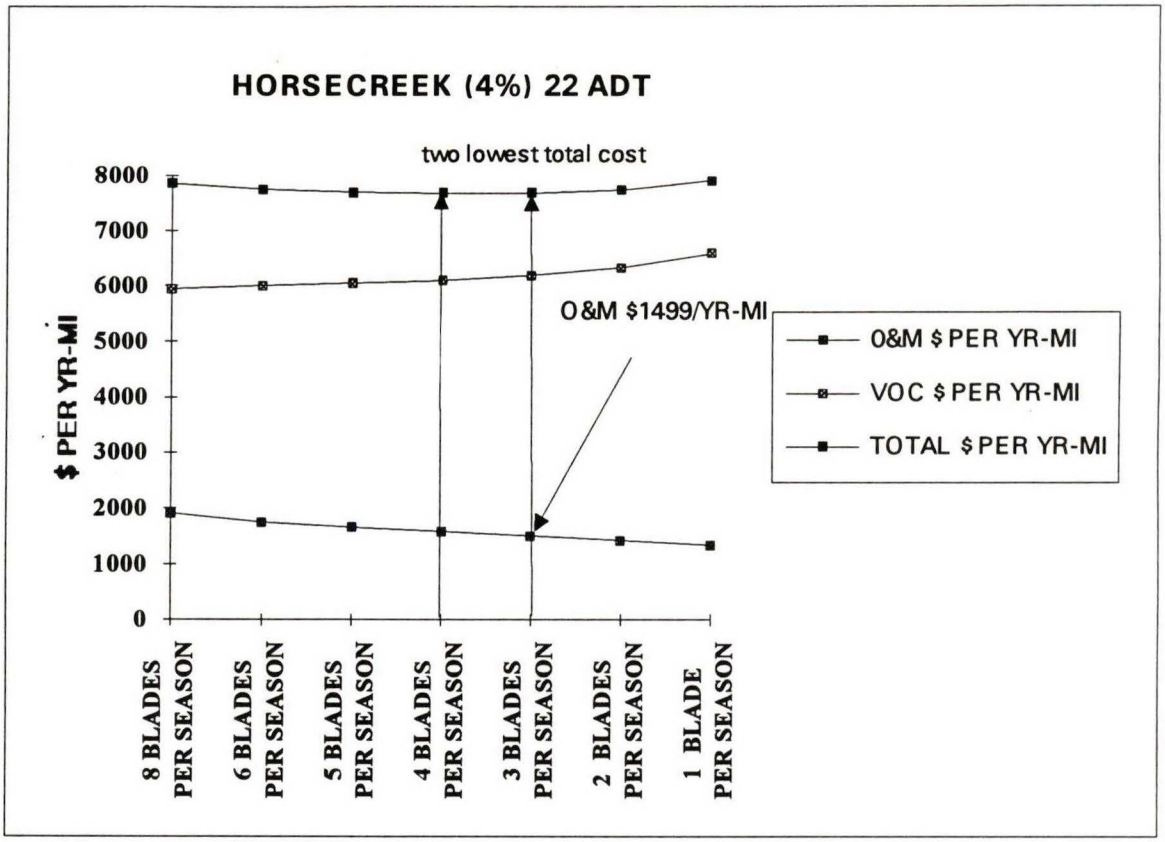
COST EFFECTIVE ANALYSIS

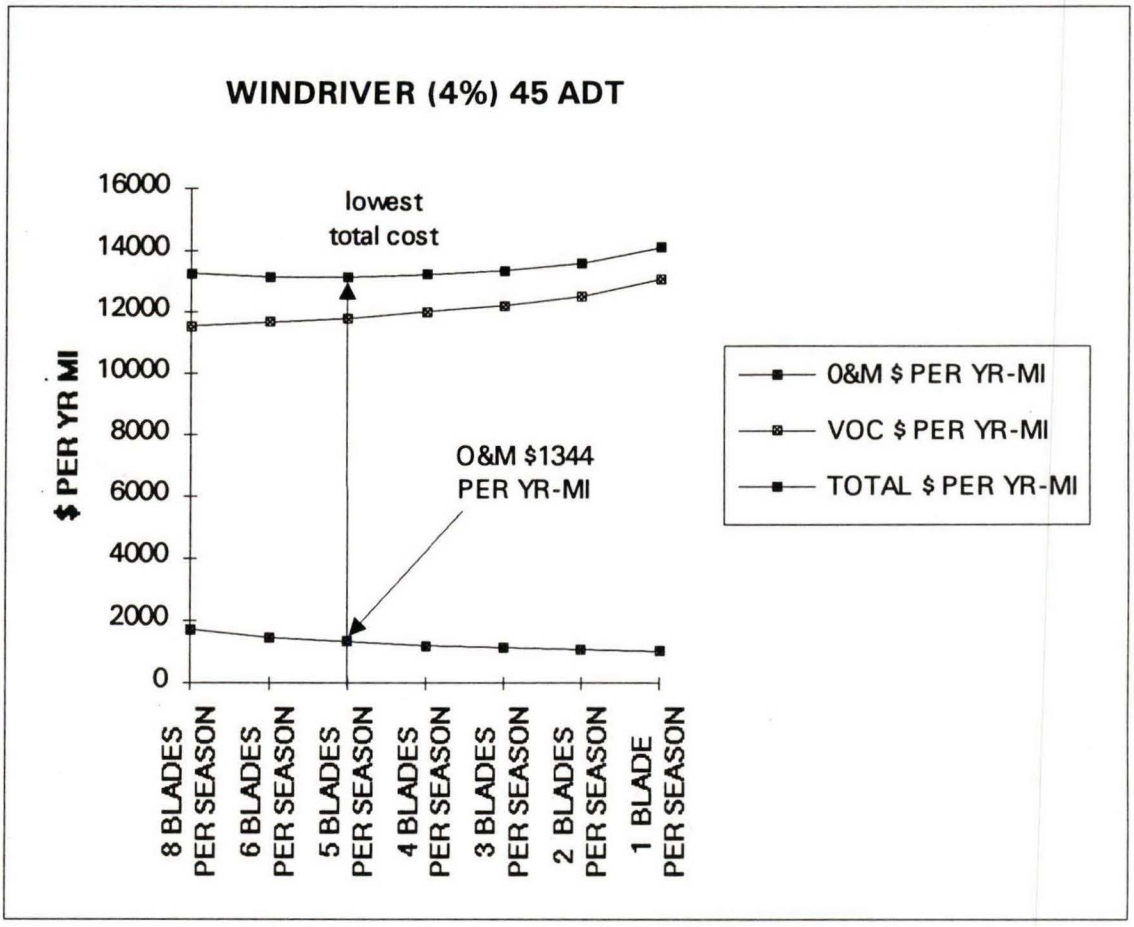
The following figures show the most cost effective maintenance policy. The cost of an increased number of bladings is balanced by a decrease in vehicle operating costs (equivalent to the minimum for both O&M cost and VOC). The Windriver roads were analyzed with 45 ADT . The Boise and Horsecreek roads were analyzed with 22 ADT. Resurfacing for all alternatives was triggered when the surface thickness was 0.4 inches with the blading frequency changing for each alternative.




BOISE ROCK RAKE (4%) 22 ADT
lowest total cost
$ PER YR-MI
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
O&M $377
PER YR-MI
O&M $ PER YR-MI
VOC $ PER YR-MI
TOTAL $ PER YR-MI
8 BLADES PER SEASON
6 BLADES PER SEASON
5 BLADES PER SEASON
4 BLADES PER SEASON
3 BLADES PER SEASON
2 BLADES PER SEASON
1 BLADE PER SEASON


BOISE DG CUSHION (4%) 22 ADT
$ PER YR-MI
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
lowest total cost
O&M $653/yr-mi
8 BLADES PER SEASON
6 BLADES PER SEASON
5 BLADES PER SEASON
4 BLADES PER SEASON
3 BLADES PER SEASON
2 BLADE PER SEASON
1 BLADE PER SEASON
O&M $ PER YR-MI
VOC $ PER YR-MI
TOTAL $ PER YR-MI


HORSECREEK (4%) 22 ADT
two lowest total cost
$ PER YR-MI
8000
7000
6000
5000
4000
3000
2000
1000
0
O&M $1499/YR-MI
8 BLADES PER SEASON
6 BLADES PER SEASON
5 BLADES PER SEASON
4 BLADES PER SEASON
3 BLADES PER SEASON
2 BLADES PER SEASON
1 BLADE PER SEASON
O&M $ PER YR-MI
VOC $ PER YR-MI
TOTAL $ PER YR-MI


WINDRIVER (4%) 45 ADT
$ PER YR MI
16000
14000
12000
10000
8000
6000
4000
2000
0
lowest
total cost
O&M $1344
PER YR-MI
8 BLADES PER SEASON
6 BLADES PER SEASON
5 BLADES PER SEASON
4 BLADES PER SEASON
3 BLADES PER SEASON
2 BLADES PER SEASON
1 BLADE PER SEASON
O&M $ PER YR-MI
VOC $ PER YR-MI
TOTAL $ PER YR-MI

SUMMARY OF OPTIMUM MAINTENANCE POLICIES

	OPTIMUM MAINTENANCE		4% DISCOUNT RATE		
	FREQUENCY OF BLADING	ADT	O&M $ PER YR-MI	VOC $ PER YR-MI	TOTAL $ PER YR-MI
BOISE AGGREGATE	3 BLADES PER SEASON	22	1212	6173	7385
BOISE DG	4 BLADES PER SEASON	22	653	6873	7526
HORSECREEK	3 BLADES PER SEASON	22	1499	6189	7688
BOISE ROCK RAKE	4 BLADES PER SEASON	22	463	7611	8074
WINDRIVER	5 BLADES PER SEASON	45	1344	11798	13141

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